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## **$W$ PLUS HEAVY QUARK PRODUCTION AT THE TEVATRON<sup>2</sup>**

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### **ABSTRACT**

We summarize the motivations for and the status of the calculation of the  $W$  + heavy quark production process in  $p\bar{p}$  colliders to Next-to-Leading Order in QCD. This process can be used to constrain the strange quark distribution function at high  $Q^2$  at the Tevatron, and also to study the bottom content of  $W + 1$  jet events. In addition, when crossed, the calculation essentially describes the single top quark production process to Next-to-Leading Order in QCD.

## **1 Introduction**

There are well-known benefits to a Next-to-Leading Order (NLO) calculation over a Leading Order (LO) one: the dependence on the renormalization and factorization scales is reduced; the parton shower starts to be reconstructed; and the calculation begins to be sensitive to detector limitations. Furthermore, the NLO calculation checks the validity of the LO one, and thus the validity of the perturbative expansion.

The motivations for the NLO calculation of the  $W$  plus heavy quark production process and its status are summarized in Section 2 and 3, respectively.

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## 2 Motivations

### 2.1 $W + charm$

This is a summary of the analysis done in Ref. 1 with the shower Monte-Carlo program Pythia [2]. At low  $Q^2$  the strange quark distribution function can be measured with the appropriate linear combination of  $F_2$  structure functions in neutrino and muon deep inelastic scattering [3]. It can also be measured from di-muon events in neutrino deep-inelastic scattering [4]. Using current experimental data sets, the two methods yield a difference of about a factor of 2 for the strange quark distribution. In Ref. 1 it was suggested that the strange quark distribution function can also be constrained by determining the charm content of  $W + 1$  jet events, because the underlying subprocess,  $sg \rightarrow W + c$ , is directly proportional to the strange quark distribution function. In this measurement the strange quark will be probed at large  $Q^2 \simeq M_W^2$ , and will therefore provide a consistency check with lower  $Q^2$  measurements. At  $Q^2 = M_W^2$  the difference between the two different strange quark distribution functions is smaller due to evolution. The bottom line is that when the relevant backgrounds are included and standard cuts are used, the factor of 2 becomes a difference of about 14%. The tagging efficiency needed for the statistical uncertainty to equal this is around 10 % for 6000  $W + 1$  jet events. There are three tagging methods available: reconstruction of a secondary vertex using an SVX [5], direct reconstruction of the decayed D-meson, and the tagging of a lepton in the semi-leptonic decay [6] of the D-meson. When combined, these methods are likely to achieve the required tagging efficiency. We refer the reader to Ref. 1 for further details.

### 2.2 $W + bottom$

As is well known, the  $W + n$  jet process with  $b$  tag is a background for the top quark analysis. Extensive studies of this background have been done at LO and with shower Monte-Carlo programs. Clearly, a comparison of the data with a NLO calculation in the case  $n = 1$  will be important. Furthermore, at large  $P_T$ , it will be necessary to include fragmentation functions.

### 2.3 $W + top$

The subprocess  $b + g \rightarrow W + t$  is a small contribution to the single top production. However, if the  $W$  is crossed to the initial state and the  $b$  to the final state and a quark leg is added to the  $W$ , one of the main contributions (esp. at LHC or larger energies) to single top production is obtained:  $q + g \rightarrow q' + t + \bar{b}$ . Our calculation contains all ingredients for the NLO analysis of

the  $W + g \rightarrow t + \bar{b}$  process. At NLO the corrections to the  $W$ -current quark vertex decouple from the rest of the graph, see Ref. 7.

## 3 Status of the NLO calculation

### 3.1 Virtual corrections

These consist of the interference between the Born diagrams and the one-loop self-energy corrections, vertex corrections, and box diagrams. Some of the contributions have singularities, and in order to regularize them, we calculated all graphs in  $d$  dimensions. A  $d$ -dimensional Passarino-Veltman reduction formalism was used<sup>1</sup> to reduce tensor- and vector-like integrals into scalar integrals. We calculated various 3- and 4-point scalar functions that were not available in the literature (due to the presence of the heavy quark and  $W$  masses). The ultraviolet singularities were absorbed through coupling-constant and mass renormalization. The part of the expression containing soft and collinear singularities factorized into a universal factor multiplying the Born cross section, because there is only one color flow for the Born diagram; in case there are several color flows, there is a different factor for each ordered subamplitude, see Ref. 9.

### 3.2 Real corrections

The contributions from all the 2 to 3 processes have to be included. Some of them exhibit soft and collinear singularities. There are several equivalent methods to deal with these singularities, see Ref. 10. These methods basically consist of separating the multi-parton phase space into a hard region, containing no singularities, and a region in which at least one of the partons is soft or emitted collinearly. In the hard phase space region, one can work in 4 dimensions and perform the integration numerically. In the soft region, the integration is done analytically, and the result again factorizes into a universal K-factor multiplying the Born cross section. In the present case, we followed the methods of Ref. 9 and derived the dependence of the K-factor on the mass of the quark. The separation of the phase space depends on one parameter (sometimes two). Each of the contributions will depend on this unphysical parameter. Of course any observable should not. The initial state collinear singularities are factorized into the distribution functions. The remaining singularities cancel against the leftover singularities of the virtual corrections.

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<sup>1</sup>We used the algebraic manipulation program FORM (Ref. 8) for much of the algebra.

Once the virtual and real corrections are summed, the cross section is constituted from terms proportional to the Born cross section, the finite part of the virtual cross section and the hard phase space part of the real corrections. At the present time, we have calculated all of the above contributions to  $W$  plus heavy quark production, and are in the process of constructing the Monte-Carlo program. It will not include detailed information on the decay of the  $W$  boson.

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